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Concrete Floors for Highway Bridges

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CONCRETE FLOORS

FOR

HIGHWAY BRIDGES

BY

JOHN IRA PARCEL

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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OF Bachelor of Science in Civil Engineering

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The use of plank floors for all ordinary highway bridges has been until quite recently the universal practice. Other kinds of floors have sometimes been used on large and costly city bridges, but such structures really form a class of their own. Within the past ten years however, the price of lumber suitable for bridge floors has increased from twenty-five to almost one hundred per cent, and at the same time the quality has undergone an even more marked deterioration. Inasmuch as there seems to be no likelihood of a radical change in the trend of the price and quality of bridge lumber, engineers and others connected with the building of highway bridges are eagerly looking for some material to take the place of wood for bridge floors. It is perhaps too soon to say that an entirely satisfactory material

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has been found; but it may be safely said that up to the present time, some form of concrete appears to be the only substitute for plank that is at all acceptable. It is the purpose of this thesis to investigate the merits and defects of concrete as a material for ordinary highway bridge floors.

The problem may be considered under two heads: New floors for old bridges, and floors for new bridges. The former is of course but a special phase of the general problem. There are many highway bridges now standing in which the steel work is good for years to come, but for which the problem of providing a concrete floor is especially difficult, because the rapid increase in the last few years in the live load which the trusses and beams are occasionally required to sustain makes the additional weight of an ordinary concrete floor more or less dangerous.

A. New Floors for Old Bridges

this part of the main problem of highway bridge floors evidently requires special investigation, and should include (1.) the maximum live load which such bridges are now called upon to sustain, and are likely to have come upon them in the near future; (2.) the possibility of the bridges standing such loads with floors not greatly heavier than the present wooden ones; (3.) the possibility of building such a floor, even though at a considerable increase in cost over what would be allowable in case of a new bridge; and (4.) comparative economy

1. Maximum Live Loads. The maximum uniformly distributed live load which a country highway bridge is required to sustain comes either from a closely packed crowd of people or herd of stock. The former is probably a little greater, it being usually estimated at about 85 pounds per square foot and the latter at about 80 pounds per square foot, but it is really doubtful if either kind of loading, to this extreme degree of intensity, ever comes

on one country highway bridge out of one hundred.

The maximum concentrated load which will come on the ordinary highway bridge is that of a heavy traction engine, and it is mainly in this respect that the live load for bridges has increased so rapidly in the last few years; and hence it is in the investigation of the effects of this kind of loading that the following discussion will consist.

Traction engines of from 20- to 25-horse-power are comparatively common nowadays in most farming communities, and even 30- to 35-horse engines are occasionally to be found; while eight or ten years ago a 16- or 18-horse engine was regarded as a "monster." The heaviest types of traction engines weigh approximately 7,000 pounds to the rated horse power. This applies to simple engines; compound engines usually weigh from 5 to 10 per cent less.

It is impossible of course to say just how much heavier

such engines will be made in the future, but judging from past experience and present demands, and what the manufacturers themselves say, it seems not unlikely that sizes somewhat larger than those above mentioned will be built.

2. Capacity of Trusses, Beams, and Floor. In considering the question of the capacity of the bridges to withstand an increase in loading, it may be noted in the beginning that highway bridges may be roughly divided into three classes; (a) bridges built for a uniformly distributed live load of 100 pounds per square foot of floor surface; (b) those built for 80 pounds per square foot of floor; and (c) those built without any scientific design. We will consider the capacity of the floor, the joists, the floor beams, and the trusses in order.

Floor. The floor plank of course will receive the greatest strain when one of the rear drivers of the traction engine is placed midway between

two adjacent joists. If the spacing of the joists is 2 feet center to center, a very common one, the effective span for the plank is but little over 20 inches, and a comparison with the safe loads given in the Cambria Hand-Book (edition of 1904, pp 362 to 367) shows that a white oak plank 3"x12" with this span should carry a load of 12,000 pounds concentrated at the center, with a factor of safety of four. Considering that the floor plank acts more or less as a continuous beam, and what is more important, that the great width of the rear drivers of the largest engines -16 to 20 inches- serves really to bring the greater part of the load on the beam near the supports, it would seem that there is little or no danger of failure of the floor, even with 2½"x10" plank.

Joists. It is usually customary in figuring the joists of a bridge floor, to assume that an oak plank, 2½ to 3 inches thick is stiff enough to distribute the

load under each wheel over at least two, and sometimes three, joists in such a manner that no one can ever get more than one half the wheel load.

Considering the effect on the joists of the 36,000-pound traction engine with axles 10 feet apart, it may be shown that for panel lengths up to 20 feet, the maximum bending moment produced is practically that due to one-half the load on one of the rear drivers (6,000 pounds) placed at the middle of the beam. If the joists are spaced 2 feet apart, and the weight of the plank floor be taken at 10 pounds per square foot of surface, the total weight the joists will have to carry will be equivalent to 12,400 pounds uniformly distributed load, which would require a 9-inch 30-pound or a 10-inch 20-pound I-beam. Some of the present bridge floors were designed for a traction engine weighing 16,000 pounds, in which case they would have an equivalent uniform load of 5,800 pounds,

which would require only a 7-inch 17½ pound beam.

A panel length of 20 feet is an extreme for the ordinary highway bridge with spans under 150 feet; and if we take a length of 15 feet as representative of the shorter panels we find that the combined weight of the floor and 36,000-pound engine is equivalent to a uniform load of 12,300 pounds; while that of the floor and the 16,000 pound engine is 5,700 pounds. The former would require a 9-inch 21-pound, and the latter a 6-inch 14¾-pound I-beam, showing a difference about the same as for the 20-foot panel above.

On Mr. Bryan's sample design of a 105-foot span highway bridge in Johnson's Modern Framed Structures the maximum concentrated load is taken as 10,000 pounds on two axles 6 feet apart, for which loading it may be easily shown by the same method of computation as above, that a 7-inch 15-pound I-beam is amply strong.

It would seem, then, that one of two things is surely true; either past methods of design have made the joists far stronger than necessary, or they are altogether unsafe under such traction engine loads as are at present common.

Floor Beams. The floor beam receives its maximum stress when the rear drivers of the engine are directly over it; and if the panel length be 20 feet, the load on the beam under each wheel is about 15,000 pounds. The maximum bending moment will occur when one wheel is placed a distance beyond the center of the beam equal to one-fourth the distance between wheels; and if l = length of floor beam, P = load under each wheel, and d = distance between wheels this moment is*:

$$M_{max.} = \frac{P}{2}\left(l - \frac{d}{2}\right)^2$$

The accuracy of this formula depends somewhat upon the relation of the spacing of the joists to the distance between the wheels, but it is in any case ac-

*Johnson's Modern Framed Structures, p. 46

curate enough for our purpose.

Assuming $l = 16$ feet, and $x = 16$ feet, the above formula shows that the effect of the 36,000-pound engine is about the same as that of a load of 38,000 pounds uniformly distributed. In the bridges built for a live load of 100 pounds per square foot, and having 20-foot panels, the total load on the floor beam is 32,000 pounds, which is the maximum load for which the beam was designed, and which is near enough to the engine load to show that there is probably little danger of actual failure under the latter. In bridges designed for a live load of 80 pounds per square foot the floor beams are figured for a distributed load of 25600 pounds, showing that in this case the engine load is about 50 per cent in excess of that for which the beam was designed.

Trusses. The effect of a traction engine on a bridge of considerable length of span approximates more or less closely to that of a fully concentrated load. It is perhaps hardly worth

while to go into very much mathematical refinement on this question; but it may not be out of place to notice that, if we consider two-thirds of the weight of the engine as concentrated on the rear axle, the maximum stress in the chords will occur under the rear wheels when the latter are beyond the center of the bridge a distance equal to one-sixth the distance between axles. The moment will be equal to*

$$P\left(\frac{l}{4}-\frac{d^2}{36l}-\frac{d}{6}\right),$$

if P = total weight of engine, l = length of span, and d = distance between axles. Most country highway bridges have a 14-foot or a 16 foot roadway, and most truss bridges are 40-foot span or over. A bridge of 40 foot span and 14-foot roadway built for a live load of 100 pounds per square foot should be able to sustain a distributed load of 56,000 pounds and from the formula above it may be shown that the equivalent uniformly distributed load of a 36,000 pound traction engine, on axles 10 feet apart is a little less than this. Of a similar mean

*Johnson's Modern Framed Structures, pp. 45-46

ver it may be shown that a bridge built for 80 pounds per square foot uniform live load is safe if the span is 50 feet and the roadway 14 feet. It would seem then, that it is only the shorter scientifically designed truss bridges, that are likely to fail, even under the load of the heaviest engine.

As an answer, therefore to our original question of whether or not the steel work in existing bridges is safe under the greatly increased concentrated live load, we may say that, assuming that the basis for the original design was not "over-safe," in all bridges built for a live load of 80 pounds per square foot, or more; (1.) oak flooring of the thickness generally used at present seems entirely safe; (2) the joists are stressed far beyond the safe limit in practically all the bridges; (3) the floor beams are stressed somewhat beyond the safe limit in most bridges; and (4) the trusses are probably amply strong in all spans exceeding 50 feet.

Any judgement passed upon bridges

which were not designed for any definite load, is just about as uncertain as their design. Some appear to be safe enough, and others have been known to fail under one-fourth the load for which they were supposed to be designed.

3. Light Weight Concrete Floors. As to the question of building a concrete floor sufficiently strong to stand the heavy concentrated loads we have been discussing, and at the same time light enough not to overstrain the already heavily loaded bridge, it may be said in the beginning that such a construction is hardly a possibility.

A plain concrete floor weighs about from 70 to 100 pounds per square foot, while an ordinary reinforced concrete floor of equal strength weighs about from 60 to 80 pounds per square foot, and even the lightest patent steel-concrete construction which would be strong enough for a bridge floor will weigh at least 40 pounds per square foot, and with the additional weight of the joists and floor beams required for the heavier floor would probably make

the total weight 43 or 44 pounds per square foot, or about 35 pounds more than the ordinary plank floor, which would mean that bridges built for 80 and 100 pounds per square foot would be reduced to a live load capacity of about 45 and 65 pounds respectively, provided the concrete floor was the very lightest weight possible. The conclusion, then, is that for existing bridges new concrete floors are an impossibility, except perhaps for some of the long span bridges built for 100 pounds per square foot. It is to be noted, too, that this condition is due almost entirely to the great weight of the present day traction engine. Except for the possibility of the occasional 18 ton load coming upon them, doubtless a light weight concrete floor could be used in many of the better class of existing highway bridges.

B. Floors for New Bridges.

The foregoing discussion would seem to show that the problem of concrete bridge floors as most engineers will have to deal with it, will be that of providing floors for new bridges.

A thorough treatment of the problem should include: (1) a description of the various possible forms of concrete floor construction, including (a) plain concrete, both slabs and arched forms; (b) reinforced concrete; (c) various patented steel concrete constructions as Buckeye, Multiplex, Roebling, etc.; (2) a comparison of the different forms with respect to strength, weight, durability, ease of construction and cost; (3) investigation of the additional weight of trusses and beams, size and spacing of joists, etc.; and (4) a comparison of the economy of wood and concrete floors, and conditions favorable to each kind of construction. The above items will be considered in the order stated.

1. Possible Forms of Concrete Floor Construction. It is the purpose now to give a brief description of the various kinds of concrete flooring.

a. Plain Concrete bridge floors are usually built in one of three ways:

First, the concrete is laid between the joists, the bottom of the floor practically coinciding with the bottom of the

joists: see Fig. 1, page 36. 16. There is of course considerable variation in the depth of the concrete in floors of this kind. If the joists are very shallow, it may be necessary for the floor to extend a considerable distance above the top of the beams to give the required strength. In some cases the forms are made so that the concrete goes a little below the bottom of the I-beams - enough to cover them completely and protect them from rust, while in other cases the top of the form coincides with the top of the lower flange of the beam.

Second, the concrete may be placed between the I-beams with its top surface curved, so that the floor acts as an arch - see Fig. 2, page 36. The I-beams are held in position by the rods when the arched form is used. This form is in the interest of economy of material, but is not a common type of floor.

Third, the other possible form of plain concrete flooring consists of concrete slabs or "artificial flagstones," - see Fig. 3, page 37. The only advantage of such a form lies in the fact that the slabs may be

made easily in large quantities in favorable weather and be stored away until desired for use, when they may be laid in place on the beams and cemented together. The beams are held in place by a tie rod as shown in Fig. 3.

b. Reinforced Concrete. The New York State Engineer, in the bulletin issued from his office called the Road Red Book, describes in detail a form of reinforced concrete slab for floors of highway bridges and culverts used extensively in that state, and recommended by him. It is similar in form and construction to the floor shown in Fig. 3, except it is reinforced and is therefore correspondingly thinner. The reinforcing consists of expanded metal cut to the size of the slab. After the concrete is mixed a layer of it 1/4 inches thick is placed in the box or form, and tamped; then the sheet of expanded metal is put in and next the remainder of the concrete. Care should be taken to mark the slabs so that no mistake will be

as to which side is reinforced when the time comes to use them.

With the same general method of reinforcing, and the same relative position of the concrete with respect to the joists the floor can be made in place in monolithic slabs extending the full width of the bridge

There are several small bridges from 18-foot to 40-foot span with reinforced concrete floor near Mansfield, Piatt County, Illinois recently built, and which seem to be very satisfactory. The concrete is made in place in slabs extending the full width of the bridge, and varying in width from 3 to 6 feet. They are laid on top of the I-beams in a manner similar to that shown in Fig. 3. The reinforcing consists of two series of $\frac{1}{2}$ inch Johnson bars, one at the bottom of the concrete spaced 6 inches apart, and the other placed $1\frac{1}{2}$ inches from the top and spaced 1 foot apart. The concrete is 6 inches thick at the center of the roadway, and 5 inches at the sides. The I-beams are spaced 2 feet apart.

center to center.

The value of the top series of bars is questionable. They are evidently intended to take the tension in the top fibre of the floor due to its acting somewhat as a continuous beam. The method is not commonly used, and any dogmatic statement concerning it is not justified. A rigorous theoretical treatment of the matter would require not only an extended and complicated discussion of the theory of continuous beams, but also a better established theory of metal reinforcement than we now have. It goes without saying that if the top series of bars are not required for the reason above mentioned, they are a detriment to the construction.

C. Steel Concrete. The heavier forms of almost any of the various kinds of steel-concrete now manufactured could be used for bridge floors. No attempt will be made to describe all the different forms, but there are three or four typical ones which have actually been used

as floors for large and expensive bridges which are worthy a brief notice.

Buckeye Floor. The Buckeye floor consists of steel troughs triangular in section as shown in section as shown in Fig. 4, page 38 and is usually built in sections of four or more triangles. When the metal is put in place, the troughs are filled with concrete and usually the latter is extended a distance of 1½ to 2½ inches above the troughs.

The Buckeye floor is manufactured by a Youngstown, Ohio company, and has been used as a floor for the following bridges in that city: The South Avenue Viaduct, a structure 1,000 feet long and 40 feet wide; the Spring Common Bridge, a 174-foot span and 40-foot roadway; the Mahoning Avenue Viaduct, 1556 feet long, 34 foot roadway; and the South Market Street Bridge, 1610 feet long, 40 foot roadway.

Roebling Floor. The Roebling system is an old and standard form of fireproof flooring which has been

used also for bridge floors. The reinforcement consists of a wire cloth sprung to arch form, and resting on the lower flanges of the steel I beams. The wire net is stiffened by steel rods ⅜ inch to 1 inch in diameter, spaced about 9 inches between centers, the rods being woven into the net, and the sheet being so placed that the rods run perpendicular to the axis of the arch. (See Fig 5, page 39) On this curved centering Portland cement concrete is deposited. The concrete is usually composed of one part Portland cement, two and one-half parts fine sand, and six parts clean cinders, and is laid on not less than three inches above the crown of the arch. For bridge floors the depth would probably be considerably greater than this. The beams are held in position by ¾ inch to ⅞ inch tie rods placed from 4 to 6 feet apart.

Multiplex Steel Concrete Floor.

This floor, manufactured in Canton, Ohio, is similar to the Buckeye floors. The troughs are from 1 to 2½ inches deeper, and of slightly different form, see Fig. 6, page 40. This floor is worthy of

construction because some prominent engineering writers, as well as the manufacturers, have claimed for it a greater capacity in proportion to its weight than any other steel concrete floor.

Trough Plate Floor. Trough plates for a steel-concrete floor, similar to those shown in Fig. 7, page 41. have been in use for a number of years for the floors of large mill buildings and train sheds, and occasionally for bridge floors. The properties of such sections, and the details, weights, and safe loads, are found in nearly all standard steel hand books.

Some sort of special finish is usually given to the top of all concrete floors. On big bridges a pavement is ordinarily laid on the concrete, while for common country highway bridges, a thin top coat of earth, gravel, or broken stone is sometimes used, though this is not at all necessary provided the surface of the concrete is roughened slightly. If the concrete is hard enough to be durable, and the surface is not roughened, it will be very slippery and

hence very objectionable.

I Comparison of Different Floors.

The data concerning the strength of the different kinds of concrete floors in proportion to their weight is very meager and much of it unreliable. According to the experiments of Mr. Davis* made in the laboratory of applied Mechanics of the University of Illinois, test specimens of a concrete floor consisting of concrete laid between 6-inch I beams, stood loads varying from 11000 to 20,000 pounds concentrated at the middle. The concrete was placed flush with the bottoms of the I-beams and 1 inch above the top, the beams being spaced 2 feet center to center. Just what the greatest concentrated load is which will ever come on an ordinary bridge floor is very uncertain; it is surely not more than 30000 pounds except in the case of a traction engine, and in this case we do not know exactly how the load is applied. If it were not for the nudging on the abutments, the effect of the latter owing to their great width would

* "Concrete Floors for Country Highway Bridges", by C. L. Davis, a thesis for the degree of B.S. in Civil Engineering, U. of I., 1904

be practically that of a distributed load but with a material as stiff as concrete, it is questionable if the effect of the mud-lugs in certain positions of the wheel is not to concentrate the whole load at the center of the driver. Granting this to be correct, it would seem that a depth of 8 inches of plain concrete would be ample, even for an 18 ton engine.

As to reinforced concrete floors, we have little to guide us, except that a number of floors have been built, and are apparently standing the loads that come upon them. One of the bridges near Mansfield (an 18 foot span) was said to have showed practically no deflection under a 16,000 pound traction engine.

The following discussion though very crude, may serve to shed some light on the subject: 5 inches may be taken as a minimum thickness for a reinforced concrete bridge floor, and a spacing of joists of 2 feet center to center a fair average. If we assume that the load on one

rear wheel of a traction engine is at some time concentrated at a point, the maximum load the floor will have to carry will be about 12,000 pounds resting at the center of the span. One of the reinforced concrete beams (No. 29) tested at the Laboratory of Applied Mechanics of the University of Illinois and described in Bulletin No. 1 of the Engineering Experiment Station, was 1 foot wide, 6 inches deep, and 12 feet long, and was reinforced with $\frac{1}{2}$ inch Johnson bars 2 inches apart, and $1\frac{1}{2}$ inches from the bottom. The span was 10 feet 8 inches, and the beam failed under a total load of 12,200 pounds, equally concentrated at the Third points of the span — equivalent roughly to a load of 8000 pounds at the center of the span. Assuming the strength of a beam to vary directly with the square of its depth, and inversely with the square of the span, a slab 1 foot wide of the usual concrete floor should stand $\frac{25}{64} \times \frac{112}{4} \times 8000$ = 87,500 pounds at the center. This leaves a factor of 7 to take care of

inferior construction, & somewhat lighter reinforcing, difference in the effect of a load concentrated practically at a point, and one concentrated along a line, and difference in manner of applying loads. It would seem from this that a depth of from 5 to 6 inches for a reasonably well constructed reinforced concrete floor is sufficient.

In regard to the strength of steel concrete floors, the manufacturers of the Buckeye floor, claim that a section of their floor showed with a span of 7 feet 8 inches and the concrete filled up to the tops of the troughs only, a capacity of 300 pounds per square foot without discernible effect, and from this they argue with a good show of reason, that with the additional layer of concrete, 2½ inches thick, which is the usual form of construction, the load could be trebled before failure. Accordingly, a 2 foot span of this floor should carry a load of 25,000 pounds concentrated at the middle. According to both the manufacturer's catalogues and the testimony of reputable engineers

the capacity of the Multiplex floor is about from 10 to 15 per cent greater than that of the Buckeye.

Some mention has previously been made of the weights of floors; fair approximate values are: 100 pounds per square foot for an 8-inch plain concrete floor; 70 pounds per square foot for a 5-inch ordinary reinforced floor; and from 40 to 60 pounds per square foot for the patent steel-concrete floors.

With respect to durability there should be practically no difference between the various kinds of floors described, as this depends almost entirely upon the proper proportioning, mixing, and laying of the concrete. The metal is entirely protected in the ordinary reinforced concrete, while in the steel-concrete constructions it is exposed and must be painted as the rest of the steel-work, so that so far as there is any difference in durability, the advantage lies with the plain and ordinary reinforced concrete.

There is very little reliable data

concerning the absolute durability of concrete bridge floors. About all we have to guide us is the wearing of concrete pavements, in the very few instances in which they have been used long enough to be fairly tested, and also the analogy we can draw from the wearing of concrete side-walks. Compared with that of city pavements or side-walks, the wear on the average country-highway bridge floor is almost insignificant; and as about ninety-five per cent of the country roads have earth surfaces, nearly all the floors soon become covered with a protective layer of earth an inch or two thick. Altogether, it seems that meagre as the facts are from which we can draw any reliable inferences, they warrant the statement that a well constructed concrete floor in a country highway bridge should last indefinitely, unless the traffic should greatly increase. City-bridges are nearly always paved, and hence in their case the question of the resistance of the concrete to di-

rect wearing is of no importance.

It is hardly safe to make any sweeping statements about the case of construction of the different floors, for there is room for considerable difference of opinion on the matter. It is generally conceded that the plain concrete floor is the easiest to build, and can be satisfactorily built without skilled labor. An ordinary reinforced floor such as has been described is of course a little more difficult to construct, but the difference is slight. The floors in the bridges near Mansfield were built by a local farmer with no technical knowledge except that gained in a few years' experience as a bridge carpenter, and some experience as a laborer on general concrete work. The workmen were nearly all farmers or farm laborers. This and other somewhat similar cases seem to show that the satisfactory construction of an ordinary reinforced concrete floor does not demand skilled labor.

A steel-concrete floor is unquestionably more difficult to lay,

though how much more cannot be stated, and further. Though some manufacturers may deny this statement, it is surely true that such a floor cannot be depended upon to develop fully its peculiar advantages unless built by skilled labor.

The relative cost of plain and reinforced concrete floors depends upon the relation of the cost of steel to the cost of concrete, the form of the floor, and other conditions, so that no definite statement can be made; but in any case, the difference is not likely to be very great. Most forms of steel-concrete are covered by letters patent, and hence are more costly than they would be by reason of materials and workmanship alone. This and the fact that skilled workmen are required to put them up satisfactorily, makes their use for most country highway bridges too expensive to be considered.

3. <u>Additional Weight of Steel Work.</u> The preceding discussion has shown that the weight per square

foot of a concrete floor suitable for the ordinary highway bridge exceeds that of a wooden floor by 50 to 90 pounds. Evidently the steel work must be considerably heavier to support this additional load, but the exact, or even approximate amount of the increase cannot be given by any definite general rule. In I-beam or girder bridges of from 18 to 36 foot span, it is inconsiderable; but for long-span truss bridges, it is very great. If a general expression could be found for the relation of the added weight of the steel to the length of span, it would be very useful as a guide in the design of the bridge floors, but owing to the variation in the types of trusses as well as in the height and panel length, this is impossible. It is important to remember in this connection that in any beam or truss under uniform load, the bending moment, and therefore, in a truss bridge, the chord stresses — varies directly not with the span, but with the square of the span, which explains why concrete floors are restricted ordinarily to the smaller bridges.

For panel lengths from 15 to 20 feet, the effect of the heavier concrete floor is unimportant. It may be shown that if the stringers be spaced 2 feet apart in a 15 foot panel, the load on one beam due to a 36,000 pound traction engine, and the dead load of an ordinary wooden floor is equivalent to about 12,200 pounds uniform load; with a concrete floor weighing 75 pounds per square foot this load is about 14,000 pounds. The difference is so small that a 9-inch 21-pound I beam would probably be used in both cases; but even if the next larger sized beam were used the added weight would be but 1¾ pounds per square foot. For these conditions, and a 16-foot roadway, the floor beam load would be increased about 40 per cent, but as the floor beam is usually built up, the increased load would probably be met by a greater depth of beam, and the increase in weight would be small.

The size and spacing of joists for a bridge with a concrete floor involves no new principles, nor has it any

except in case the concrete is laid between the joists, when the question of the size and spacing of the later becomes an important and difficult problem. It is unfortunate that we know too little about the action of the stresses in a combined mass of steel and concrete to discuss the problem intelligently from a purely theoretical standpoint, while no experiments have been made so far that could be used as a basis for an empirical solution.

4. Comparison of Wood and Concrete Floors — Conclusion. The almost insuperable difficulty which we meet in attempting to discuss the question of plank versus concrete bridge floors is that the cost of wood and concrete varies so with the locality and conditions that it is hardly possible to give even rough average figures. A comparison of the tables given by Major Black* shows that as long ago as 1894 the price of ordinary oak lumber varied from $10.00 per thousand in Oregon, to $35.00 per thousand in New Jersey. The price

*"United States Public Works", by Major William Black.

of cement varies considerably in different parts of the United States, and the cost of sand, gravel, and broken stone varies a good deal more. Mr. Davis* suggests, as approximate working values, that an ordinary plank floor should cost from 7 to 10 cents, and the form of concrete floor shown in Fig. 1 from 10 to 12 cents per square foot. It is claimed by some highway commissioners in central Illinois that the plank which are at present used for bridge floors cannot be depended upon to last more than five or six years. Under these conditions the concrete floor would surely seem to possess a decided economic advantage for I-beam and girder bridges, and probably for most truss bridges under 100 foot span. This is given by the New York State Engineer as about the limiting length of span for the ordinary country bridge. Of course, high-priced lumber, cheap sand and gravel or broken stone, and heavy traffic, all tend to make the use of concrete especially advantageous.

* "Concrete Floors for Country Highway Bridges," by E. F. Davis.

In conclusion, we may repeat the saying that this is "the age of concrete." Lumber is steadily advancing in price, and with the depletion of our our forests, will almost surely continue to do so for many years. Concrete, on the other hand, owing to improved machinery for mixing, and improved methods of cement manufacture, is growing cheaper, and its properties are becoming much better understood by engineers, thus making possible much more economic design. The rapidity and extent of the development in the use of concrete during the past ten years is little short of marvelous, and we may reasonably expect that before many more years have passed, it will have added the field of short and medium span highway bridge floors to the many fields it has already conquered.

Fig. 1. Floor with Plain Concrete laid between the Joists

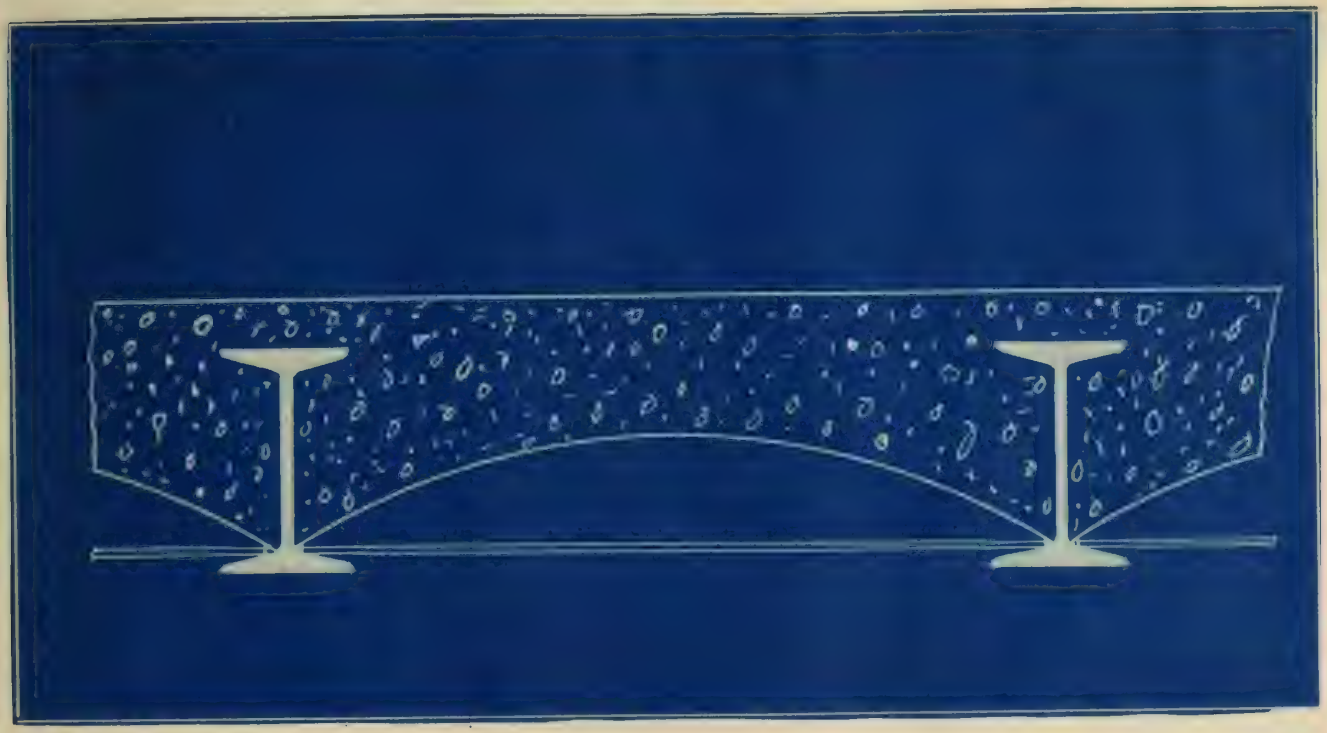
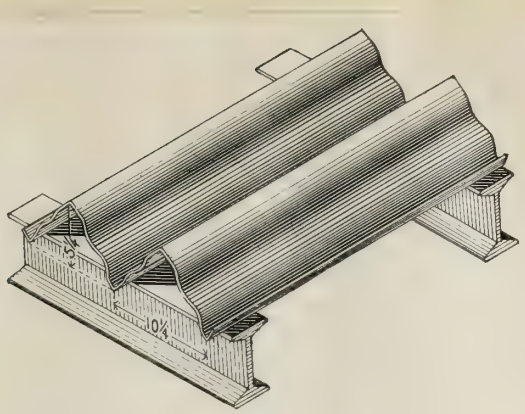


Fig 2. Arched Plain Concrete Floor

Fig. 3. Floor with Plain Concrete Slabs Laid on Top of Joists



(Patented.)

Fig. 54.

Skeleton View of Trough Laid on I Beams.

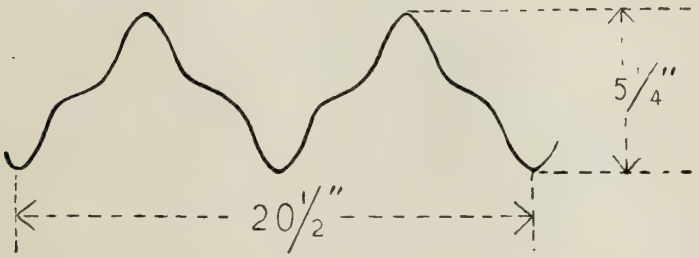


Fig. 54½.

End View.

Fig 4 - Buckeye Steel-Concrete Floor

System A—Arch Construction.

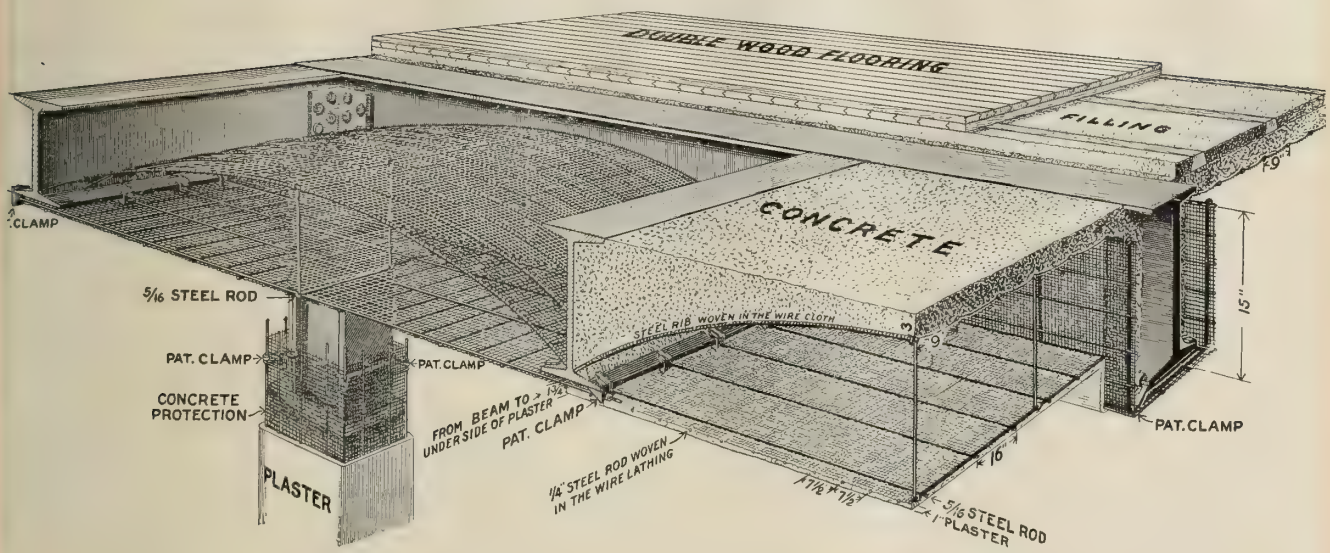
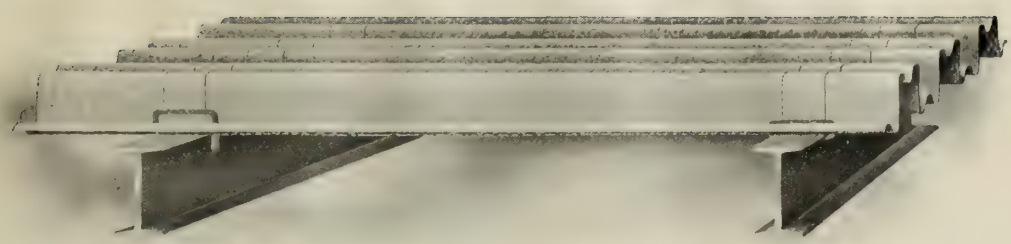


Fig. 5. Roebling Steel-Concrete Floor



"A"

The Multiplex Steel Plate used in its simplest form.

"B"

The Multiplex Steel Plate with end bearings on lower flange of "I" beams.

Fig. 6. Multiplex Steel-Concrete Floor

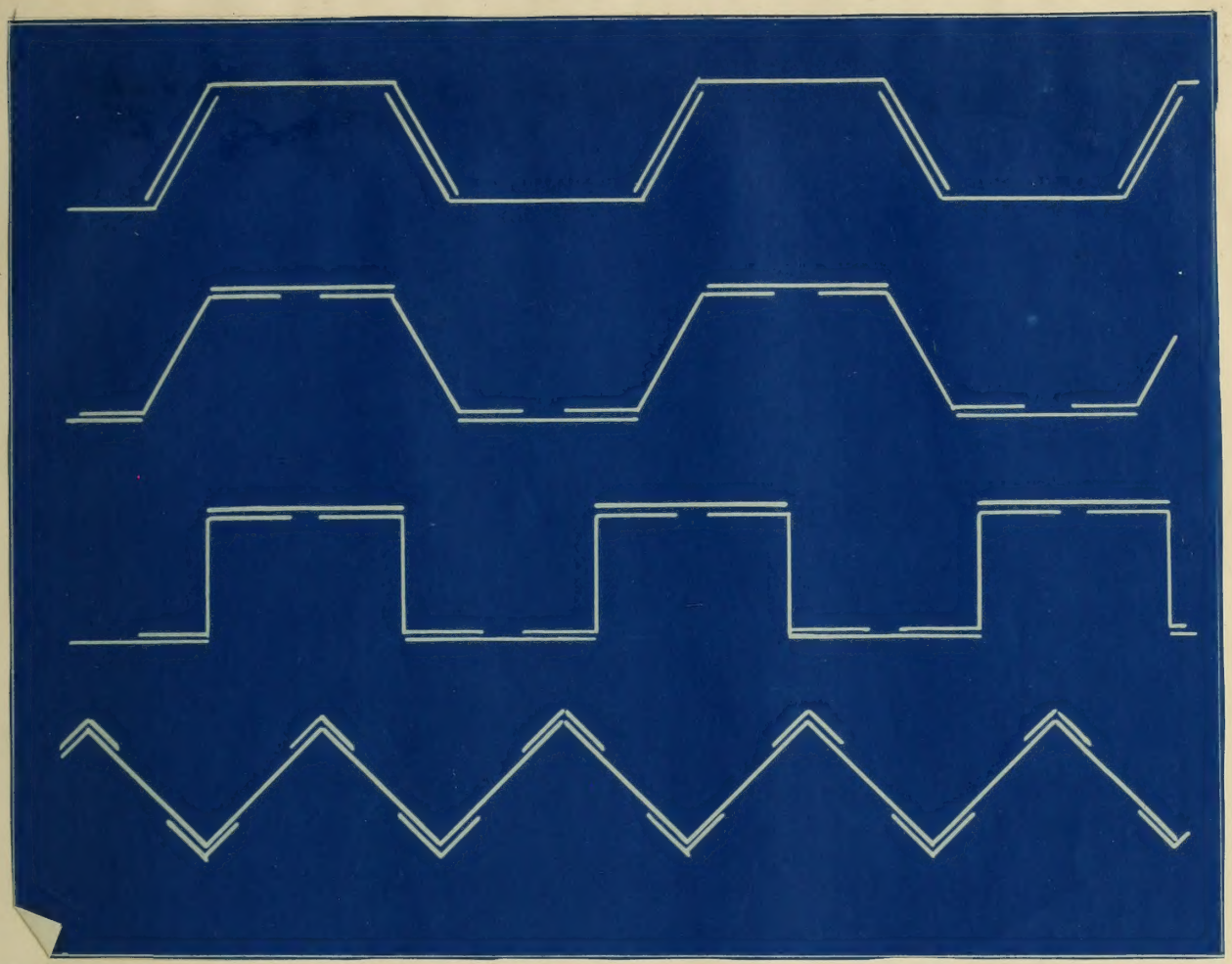


Fig. 7. Trough Plates for Steel Concrete Floor

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